IFT-P.076/99

Single Production of Leptoquarks at the Tevatron

O. J. P. Éboli* and T. L. Lungov†

Instituto de Física Teórica – UNESP

R. Pamplona 145, 01405-900 São Paulo, Brazil

Abstract

We study the single production of first generation leptoquarks in association with a $e^{\pm}$ at the Fermilab Tevatron. We focus our attention on final states exhibiting a $e^{+}e^{-}$ pair and jets, and perform a detailed analyses of signal and backgrounds. The single leptoquark production cross section depends on the leptoquark Yukawa coupling to lepton-quark pairs and we show that the study of this mode can extend considerably the leptoquark search for a large range of these couplings. In fact, for Yukawa couplings of the electromagnetic strength, the combined results of the Tevatron experiments can exclude the existence of leptoquarks with masses up to 260–285 (370–425) GeV at the RUN I (RUN II), depending on their type.

*Email: eboli@ift.unesp.br

†Email: thais@ift.unesp.br

I. INTRODUCTION

Leptoquarks are an undeniable signal of physics beyond the standard model (SM), and consequently, there have been several direct searches for them in accelerators. In fact, many theories that treat quarks and leptons in the same footing, like composite models [1,2], technicolor [3], and grand unified theories [4], predict the existence of new particles, called leptoquarks, that mediate quark-lepton transitions. Since leptoquarks couple to a lepton and a quark, they are color triplets under $SU(3)_C$, carry simultaneously lepton and baryon number, have fractional electric charge, and can be of scalar or vector nature.

From the experimental point of view, leptoquarks possess the striking signature of a peak in the invariant mass of a charged lepton with a jet, which make their search rather simple without the need of intricate analyses of several final state topologies. So far, all leptoquark searches led to negative results. At the hadron colliders, leptoquarks can be pair produced by gluon–gluon and quark–quark fusions, as well as singly produced in association with a lepton in gluon–quark reactions. At the Tevatron, the CDF and DØ collaborations studied the pair production of leptoquarks which decay into electron-jet pairs [5]. The combined CDF and DØ limit on the leptoquark mass is $M_{\rm lq} > 242$ GeV [6] for scalar leptoquarks decaying exclusively into $e^{\pm}$–jet pairs. At HERA, first generation leptoquarks are produced in the s–channel through their Yukawa couplings, and the HERA experiments [7] placed limits on their masses and couplings, establishing that $M_{lq} \gtrsim 215 - 275$ GeV depending on the leptoquark type.

In this work we studied the single production of first generation leptoquarks (S) in association with a charged lepton at the Tevatron [8], *i.e.*

$$p\bar{p} \rightarrow S\ e^{\pm} \rightarrow e^{+}e^{-} \text{ jets} \quad . \tag{1}$$

We performed a careful analyses of all possible QCD and electroweak backgrounds for the topology exhibiting jets plus a e^+e^- pair using the event generator PYTHIA [9]. The signal was also generated using this package. We devised a series of cuts not only to reduce

the background, but also to enhance the signal. Since the available phase space for single production is larger than the one for double production, we show that the single leptoquark search can extend considerably the Tevatron bounds on these particles. Our results indicate that the combined results of the Tevatron experiments can exclude the existence of leptoquarks with masses up to 260–285 (370–425) GeV at the RUN I (RUN II), depending on their type, for Yukawa couplings of the electromagnetic strength.

It is interesting to notice that pair production of scalar leptoquarks in a hadronic collider is essentially model independent since the leptoquark–gluon interaction is fixed by the $SU(3)_C$ gauge invariance. On the other hand, single production is model dependent because it takes place via the unknown leptoquark Yukawa interactions. Notwithstanding, these two signals for scalar leptoquarks are complementary because they allow us not only to reveal their existence but also to determine their properties such as mass and Yukawa couplings to quarks and leptons. In this work, we also studied the region in the parameter space where the single leptoquark production can be isolated from the pair production.

The outline of this paper is as follows. In Sec. II we introduce the $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ invariant effective Lagrangians that we analyzed. We also discuss in this section the main features of the leptoquark signal and respective backgrounds. We present our results in Sec. III while our conclusions are drawn in Sec. IV.

II. LEPTOQUARK SIGNALS AND BACKGROUNDS

We assumed that scalar–leptoquark interactions are $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ gauge invariant above the electroweak symmetry breaking scale v. Moreover, leptoquarks must interact with a single generation of quarks and leptons with chiral couplings in order to avoid the low energy constraints [10,11]. The most general effective Lagrangian satisfying these requirements and baryon number (B), lepton number (L), electric charge, and color conservations is [12]

$$\mathcal{L}_{eff} = \mathcal{L}_{F=2} + \mathcal{L}_{F=0} \ , \tag{2}$$

$$\mathcal{L}_{F=2} = g_{1L}\ \bar{q}^c_L\ i\tau_2\ \ell_L\ S_{1L} + g_{1R}\ \bar{u}^c_R\ e_R\ S_{1R} + \tilde{g}_{1R}\ \bar{d}^c_R\ e_R\ \tilde{S}_1$$
$$+\ g_{3L}\ \bar{q}^c_L\ i\tau_2\ \vec{\tau}\ \ell_L \cdot \vec{S}_3 \ , \tag{3}$$
$$\mathcal{L}_{F=0} = h_{2L}\ R^T_{2L}\ \bar{u}_R\ i\tau_2\ \ell_L + h_{2R}\ \bar{q}_L\ e_R\ R_{2R} + \tilde{h}_{2L}\ \tilde{R}^T_2\ \bar{d}_R\ i\tau_2\ \ell_L \ , \tag{4}$$

where $F = 3B + L$, q (ℓ) stands for the left-handed quark (lepton) doublet, and we omitted the flavor indices of the leptoquark couplings to fermions. The leptoquarks $S_{1R(L)}$ and $\tilde{S}_1$ are singlets under $SU(2)_L$, while $R_{2R(L)}$ and $\tilde{R}_2$ are doublets, and S_3 is a triplet.

From the above interactions we can see that first generation leptoquarks can decay into pairs $e^\pm q$ and $\nu_e q'$, thus, giving rise to a $e^\pm$ plus a jet, or a jet plus missing energy. However, the branching ratio of leptoquarks into these final states depends on the existence of further decays, *e.g.* into new particles. In this work we considered only the $e^\pm q$ decay mode and that the branching ratio into this channel (β) is a free parameter. As we can see from Eqs. (3) and (4), only the leptoquarks R^2_{2L}, $\tilde{R}^2_2$ and S^-_3 decay exclusively into a jet and a neutrino, and consequently can not give rise to the topology that we are interested in.

The event generator PYTHIA assumes that the leptoquark interaction with quarks and leptons is described by

$$\bar{e}\ (a + b\gamma_5)\ q \ , \tag{5}$$

and the leptoquark cross sections are expressed in terms of the parameter κ defined as

$$\kappa\ \alpha_{\rm em}\ \equiv\ \frac{a^2 + b^2}{4\pi} \tag{6}$$

with $\alpha_{\rm em}$ being the fine structure constant. We present our results in terms of the leptoquark mass M_{lq} and κ, being trivial to translate κ into the coupling constants appearing in Eqs. (3) and (4); see Table I. The subprocess cross section for the associated production of a leptoquark and a charged lepton

$$q + g \to S + \ell \ , \tag{7}$$

depends linearly on the parameter κ defined in Eq. (6). For the range of leptoquark masses accessible at the Tevatron, leptoquarks are rather narrow resonances with their width given by

$$\Gamma(S \to \ell q) = \frac{\kappa \alpha_{\rm em}}{2} M_{\rm lq} \quad . \tag{8}$$

At the parton level, the single production of leptoquarks leads to a final state exhibiting a pair e^+e^- and q ($\bar{q}$). After the parton shower and hadronization the final state usually contains more than one jet. An interesting feature of the final state topology e^+e^- and jets is that the double production of leptoquarks also contribute to it. Consequently, the topology e^+e^-–jets has a cross section larger than the pair or single leptoquark productions alone, increasing the reach of the Tevatron. In principle we can separate the single from the double production, for instance, requiring the presence of a single jet in the event. However, in the absence of any leptoquark signal, it is interesting not to impose this cut since in this case the signal cross section gets enhanced, leading to more stringent bounds.

We exhibit in Table II the total cross section for the single production of leptoquarks that couple only to $e^\pm u$ or $e^\pm d$ pairs, assuming $\kappa = 1$ and $\beta = 1$ and requiring one electron with $p_T > 50$ GeV, another one with $p_T > 20$ GeV, and $|\eta| < 4.2$ for both $e^\pm$. Notice that the cross sections for the single production of e^+q and e^-q leptoquarks, that is $|F| = 0$ or 2, are equal at the Tevatron. Furthermore, the cross section for the single production of a leptoquark coupling only to u quarks is approximately twice the one for leptoquarks coupling only to d quarks, in agreement with a naive valence–quark–counting rule. We display in Table III the production cross section of leptoquark pairs for the same choice of the parameters and cuts used in Table II. The small difference between the cross sections for the production of $e^\pm u$ and $e^\pm d$ leptoquarks is due to the exchange of a $e^\pm$ in the t–channel of the reaction $q\bar{q} \to S\bar{S}$.

In our analyses we kept track of the $e^\pm$ (jet) carrying the largest transverse momentum, that we denoted by e_1 (j_1), and the $e^\pm$ (jet) with the second largest p_T, that we called e_2 (j_2). The reconstruction of the jets in the final state was done using the subroutine LUCELL of PYTHIA, requiring the transverse energy of the jet to be larger than 7 GeV inside a cone $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$.

The transverse momentum distributions of the e_1 and j_1 originating from leptoquarks

are shown in Fig. 1, where we required that $p_T^{e_1} > 50$ GeV, $p_T^{e_2} > 20$ GeV, and $|\eta| < 4.2$ for both $e^\pm$. In this figure, we added the contributions from single and pair production of ue^- leptoquarks of mass $M_{\rm lq} = 300$ GeV for $\sqrt{s} = 2.0$ TeV. We can see from this figure that the e_1 and j_1 spectra are peaked approximately at $M_{\rm lq}/2$ and exhibit a large fraction of hard leptons, and consequently the p_T cut on e_1 does not reduce significantly the signal.

Within the scope of the SM, there are many sources of backgrounds leading to jets accompanied by a pair e^+e^-. We divided them into three classes [13]:

- *QCD processes:* The reactions included in the QCD class are initiated by hard scatterings proceeding exclusively through the strong interaction. In this class of processes, the main source of hard $e^\pm$ is the semileptonic decay of hadrons possessing quarks c or b, which are produced in the hard scattering or in the parton shower through the splitting $g \to c\bar{c}$ $(b\bar{b})$. Important features of the events in this class are that close to the hard $e^\pm$ there is a substantial amount of hadronic activity and that the $e^\pm$ transverse momentum spectrum is peaked at small values.

- *Electroweak processes:* This class contains the Drell-Yan production of quark/lepton pairs and the single and pair productions of electroweak gauge bosons. It is interesting to notice that the main backgrounds by far in this class are $q_i g$ $(\bar{q}_i) \to Z q_i$ (g). This suggests that we should veto events where the invariant mass of the e^+e^- pair is around the Z mass; however, even after such a cut, these backgrounds remain important due to the production of off-shell Z's.

- *Top production:* The production of top quark pairs takes place through quark–quark and gluon–gluon fusions. In general, the $e^\pm$ produced in the leptonic top decay into $be\nu_e$ are rather isolated and energetic. Fortunately, the top production cross section at the Tevatron is rather small.

As an illustration, we present in Table IV the total cross section of the above background classes requiring the events to exhibit a $e^\pm$ with $p_T > 50$ GeV and a second $e^\mp$ having $p_T > 20$

GeV with the invariant mass of this pair differing from the Z mass by more than 5 GeV. As we can see from this table, the introduction of this p_T cut already reduces the QCD backgrounds to a level below the electroweak processes without on–mass-shell production of Z's. As we naively expect, the increase in the center–of–mass energy has a great impact in the top production cross section.

III. RESULTS

Taking into account the features of the signal and backgrounds, we imposed the following set of cuts:

(C1) We required the events to exhibit a pair e^+e^- and one or more jets.

(C2) We introduced typical acceptance cuts – that is, the $e^\pm$ are required to be in the rapidity region $|\eta_e| < 2.5$ and the jet(s) in the region $|\eta_j| < 4.2$.

(C3) One of the $e^\pm$ should have $p_T > 50$ GeV and the other $p_T > 20$ GeV.

(C4) The $e^\pm$ should be isolated from hadronic activity. We required that the transverse energy deposited in a cone of size $\Delta R = 0.5$ around the $e^\pm$ direction to be smaller than 10 GeV.

(C5) We rejected events where the invariant mass of the pair e^+e^- ($M_{e_1e_2}$) is close to the Z mass, *i.e.* we demanded that $|M_{e_1e_2} - M_Z| < 30$ GeV. This cut reduces the backgrounds coming from Z decays into a pair e^+e^-.

(C6) We required that *all* the invariant masses $M_{e_ij_k}$ (i, $k = 1$, 2) are larger than 10 GeV.

(C7) We accepted only the events which exhibit a pair $e^\pm$–jet with an invariant mass M_{ej} in the range $|M_{ej} - M_{\text{lq}}| < 30$ GeV. An excess of events signals the production of a leptoquark.

In Fig. 2 we present the M_{ej} spectrum after the cuts (C1)–(C6) originating from the background and the production of a e^+u leptoquark of mass 250 GeV with $\kappa = \beta = 1$. The largest invariant mass of the four possible combinations is plotted both for background (dashed line) and signal (solid line). The signal peak is clearly seen out of the background.

A. Pair production

At this point it is interesting to obtain the attainable bounds on leptoquarks springing from the search of leptoquark pairs. In this case we required, in addition to cuts (C1)–(C7), that the events present two $e^\pm$–jet pairs with invariant masses satisfying $|M_{ej} - M_{\rm lq}| < 30$ GeV. Our results show that CDF and DØ should be able to constrain the leptoquark masses to be heavier than 225 (350) GeV at the RUN I (RUN II) for $\beta = 1$ and $\kappa = 0$, assuming that only the background is observed. When the data of both experiment are combined, the limit changes to 250 (375) GeV. It is interesting to notice that our results for the RUN I are compatible with the ones obtained by the Tevatron collaborations [14]. Moreover, taking into account the single production of leptoquarks changes these constraints only by a few GeV for $\kappa = 1$.

B. Single production

We display in Fig. 3 the total background cross section and its main contributions as a function of M_{lq} after applying the cuts (C1)–(C7) for center–of–mass energies of 1.8 and 2.0 TeV. We can see from this figure that the number of expected background events per experiment at the RUN I (II) is 4 (102) for $M_{\rm lq} = 200$ GeV dropping to 0 (8) for $M_{\rm lq} =$ 400 GeV. For the sake of comparison, we display in Fig. 4 the total cross section for the production of e^+u and e^-d leptoquarks assuming $\kappa = 1$ and $\beta = 1$ for the same cuts and center–of–mass energies.

We estimated the capability of the Tevatron to exclude regions of the plane $\kappa\beta \otimes M_{\rm lq}$ assuming that only the background events were observed. We present in Fig. 5a the projected

95% CL exclusion region for e^+u and e^+d leptoquarks at the RUN I with an integrated luminosity of 110 pb^{-1} per experiment. From our results we can learn that the search for single $e^\pm u$ ($e^\pm d$) leptoquarks in each experiment can exclude leptoquark masses up to 265 (245) GeV for $\kappa\beta = 1$. Combining the results of CDF and DØ expands this range of excluded masses to 285 (260) GeV respectively. The corresponding results for the RUN II with an integrated luminosity of 2 fb^{-1} per experiment are presented in Fig. 5b. Here we can see that the combined CDF and DØ data will allow us to rule out $e^\pm u$ ($e^\pm d$) leptoquarks with masses up to 425 (370) GeV, assuming that $\beta = \kappa = 1$.

It is important to stress that events exhibiting a pair of leptoquarks also contribute to our single leptoquark search. This is the reason why lighter leptoquarks can be observed even for arbitrarily small κ; see Figs. 5. However, the maximum mass that can be excluded for $\kappa = 0$ is smaller than the limit coming from the search for leptoquark pairs since the requirement of an additional $e^\pm$–jet pair with invariant mass close to $M_{\rm lq}$ helps to further reduce the backgrounds. For instance the single leptoquark search can rule out leptoquarks with masses up to 330 GeV for $\kappa = 0$ at RUN II while the search for leptoquark pairs leads to a lower bound of 375 GeV.

In principle we can separate the double production of leptoquarks from the single one. An efficient way to extract the single leptoquark events is to require that just one jet is observed. At the RUN I this search leads to an observable effect only for rather large values of κ. On the other hand, this search can be done at the RUN II, however, the bounds coming from this analysis are weaker than the ones obtained above; see Fig. 6. We can interpret this figure as the region of the $\kappa\beta \otimes M_{\rm lq}$ where we can isolat the single leptoquark production and study this process in detail.

IV. CONCLUSIONS

The analyses of the single production of leptoquarks at the Tevatron RUN I allow us to extend the range of excluded masses beyond the present limits stemming from the search

of leptoquark pairs. We showed that in the absence of any excess of events CDF and DØ individually should be able to probe $e^{\pm}u$ ($e^{\pm}d$) leptoquark masses up to 265 (245) GeV for Yukawa couplings of the electromagnetic strength and $\beta = 1$. In the case $\beta = 0.5$ these limits reduce to 250 (235) GeV. Moreover, combining the results from both experiments can further increase the Tevatron reach for leptoquarks. Assuming that leptoquarks decay exclusively into the known quarks and leptons and $\kappa = 1$, the combined Tevatron results can exclude S_{1L} and S_3^0 leptoquarks with masses up to 270 GeV, S_{1R}, R_{2L}^1, and R_{2R}^1 leptoquarks with masses 285 GeV, and $\tilde{S}_{1R}$, S_3^+, R_{2R}^2, and $\tilde{R}_2^1$ with masses up to 260 GeV. This results represent an improvement over the present bounds obtained at the Tevatron [5], however, the bounds are similar to the ones obtained by the HERA collaborations [7].

At the RUN II, the search for the single production of leptoquarks will be able to rule out leptoquarks with masses even larger. For instance, the CDF and DØ combined results can probe $e^{\pm}u$ ($e^{\pm}d$) leptoquark masses up to 425 (370) GeV for $\kappa\beta = 1$. In the case $\kappa\beta = 0.5$, these bounds reduce to 385 (350) GeV. However, even these improved limits will not reach the level of the indirect bounds ensuing from low energy physics [10,11,15]. Direct limits more stringent than the indirect ones will only be available at the LHC [13,16] or future e^+e^- colliders [17].

ACKNOWLEDGMENTS

This work was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), and by Programa de Apoio a Núcleos de Excelência (PRONEX).

REFERENCES

[1] For a review see, W. Buchmüller, Acta Phys. Austr. Suppl. **XXVII**, 517 (1985).

[2] L. Abbott and E. Farhi, Nucl. Phys. **B189**, 547 (1981).

[3] S. Dimopoulos, Nucl. Phys. **B168**, 69 (1981); E. Farhi and L. Susskind, Phys. Rev. D**20**, 3404 (1979); J. Ellis *et. al.*, Nucl. Phys. **B182**, 529 (1981).

[4] See, for instance, P. Langacker, Phys. Rep. **72**, 185 (1981); J. L. Hewett and T. G. Rizzo, Phys. Rep. **183**, 193 (1989).

[5] CDF Collaboration, F. Abe *et al.*, Phys. Rev. D**48**, 3939 (1993); Phys. Rev. Lett. **75**, 1012 (1995); DØ Collaboration, S. Abachi *et al.*, Phys. Rev. Lett. **72**, 965 (1994); *ibid.* **75**, 3618 (1995); CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **79**, 4327 (1997); CDF Collaboration, F. Abe *et. al.*, Phys. Rev. Lett. **78**, 2906 (1997); DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **79**, 4321 (1997); Phys. Rev. Lett. **80**, 2051 (1998).

[6] C.Grosso-Pilcher *et al.*, CDF Collaboration and DØ Collaboration, preprint FERMILAB-PUB-98-312-E (hep-ex/9810015).

[7] ZEUS Collaboration, M. Derrick *et al.*, Phys. Lett. **B306**, 173 (1993); H1 Collaboration, I. Abt *et al.*, Nucl. Phys. **B396**, 3 (1993); H1 Collaboration, S. Aid *et al.*, Phys. Lett. **B369**, 173 (1996); H1 Collaboration, C. Adloff *et al.*, Z. Phys. **C74**, 191 (1997); ZEUS Collaboration, J. Breitweg *et al.*, Z. Phys. **C74**, 207 (1997).

[8] J. L. Hewett and S. Pakvasa, Phys. Rev. D**37**, 3165 (1988); O. J. P. Éboli and A. V. Olinto, Phys. Rev. D**38**, 3461 (1988); B. Dion, L. Marteau, and G. Simon, Phys. Rev. D**56**, 479 (1997).

[9] T. Sjöstrand, Computer Phys. Commun. **82**, 74 (1994).

[10] O. Shanker, Nucl. Phys. **B204**, 375 (1982).

[11] W. Buchmüller and D. Wyler, Phys. Lett. **B177**, 377 (1986); J. C. Pati and A. Salam,

Phys. Rev. D**10**, 275 (1974).

[12] W. Buchmüller, R. Rückl, and D. Wyler, Phys. Lett. **B191**, 442 (1987).

[13] O. J. P. Éboli, R. Z. Funchal, and T. L. Lungov, Phys. Rev. D**57**, 1715 (1998).

[14] CDF and DØ collaborations use the NLO pair production cross sections in their analyses, while we use the tree level expression. The difference in the cross sections compensates the fact that we did not consider detection efficiencies and detector resolution.

[15] S. Davidson, D. Bailey, and A. Campbell, Z. Phys. **C61**, 613 (1994); G. Bhattacharyya, J. Ellis, and K. Sridhar, Phys. Lett. **B336**, 100 (1994); erratum *ibid.* **B338**, 522 (1994); O. J. P. Éboli, M. C. Gonzalez-Garcia, and J. K. Mizukoshi, Nucl. Phys. **B443**, 20 (1995); M. Leurer, Phys. Rev. Lett. **71**, 1324 (1993); Phys. Rev. D**49**, 333 (1994).

[16] J. Ohnemus, S. Rudaz, T. F. Walsh, and P. Zerwas, Phys. Lett. **B334**, 203 (1994); O. J. P. Éboli and J. E. Cieza Montalvo, Phys. Rev. D**50**, 331 (1994). J. Blümlein, E. Boos, and A. Krykov, Z. Phys. **C76**, 137 (1997); M. Krämer, *et al.*, Phys. Rev. Lett. **79**, 341 (1997); J. L. Hewett and T. Rizzo, Phys. Rev. D**56**, 5709 (1997); M. S. Berger and W. Merritt, hep-ph/9611386; J. E. Cieza Montalvo *et al.*, Phys. Rev. D**58**, 095001 (1998); B. Dion, *et al.*, Eur. Phys. J. **C2**, 497 (1998); B. Dion, L. Marleau, and G. Simon, Phys. Rev. D**59**, 015001 (1999)

[17] J. L. Hewett and T. G. Rizzo, Phys. Rev. D**36**, 3367 (1987); J. L. Hewett and S. Pakvasa Phys. Lett. **B227**, 178 (1987); J. E. Cieza and O. J. P. Éboli, Phys. Rev. D**47**, 837 (1993); J. Blümein and R. Rückl, Phys. Lett. **B304**, 337 (1993); J. Blümlein, E. Boos, and A. Krykov, Phys. Lett. **B392**, 150 (1997); M. S. Berger, hep-ph/9609517; F. Cuypers, P. H. Frampton, and R. Rueckl, Phys. Lett. **B390**, 221 (1997); O. J. P. Éboli *et al.*, Phys. Lett. **B311**, 147 (1993); H. Nadeau and D. London, Phys. Rev. D**47**, 3742 (1993); M. A. Doncheski and S. Godfrey, Phys. Rev. D**51**, 1040 (1995); T. M. Aliev, E. Iltan, and N. K. Pak, Phys. Rev. D**54**, 4263 (1996); M. A. Doncheski and S.

Godfrey, hep-ph/9612385; G. Bélanger, D. London, and H. Nadeau, Phys. Rev. D**49**, 3140 (1994).

TABLES

leptoquark	decay	branching ratio	$4\pi\alpha_{\rm em}\kappa$
S_{1L}	$e^+\bar{u}$	50%	$\frac{g_{1L}^2}{2}$
S_{1R}	$e^+\bar{u}$	100%	$\frac{g_{1R}^2}{2}$
$\tilde{S}_{1R}$	$e^+\bar{d}$	100%	$\frac{\tilde{g}_{1R}^2}{2}$
S_3^+	$e^+\bar{d}$	100%	g_3^2
S_3^0	$e^+\bar{u}$	50%	$\frac{g_3^2}{2}$
R_{2L}^1	$e^-\bar{u}$	100%	$\frac{h_{2L}^2}{2}$
R_{2R}^1	$e^-\bar{u}$	100%	$\frac{h_{2R}^2}{2}$
R_{2R}^2	$e^-\bar{d}$	100%	$\frac{h_{2R}^2}{2}$
$\tilde{R}_2^1$	$e^-\bar{d}$	100%	$\frac{\tilde{h}_{2L}^2}{2}$

TABLE I. Leptoquarks that can be observed through their decays into a $e^\pm$ and a jet and the correspondent branching ratios into this channel assuming that there are no new particles. We also show the relation between the leptoquark Yukawa coupling and the parameter κ used in PYTHIA.

ℓq coupling	$M_{\rm lq} = 200$ GeV	250 GeV	300 GeV	350 GeV
$e^\pm u$	187./259.	59./86	20./30	–/12.
$e^\pm d$	77./112.	22./34	7./11.	–/4.

TABLE II. Total cross section in fb for the single production of a leptoquark that couples only to ℓq pairs for several leptoquark masses and center–of–mass energies of 1.8/2.0 TeV. We required that one $e^\pm$ has $p_T > 50$ GeV, the other one $p_T > 20$ GeV, and $|\eta| < 4.2$ for both $e^\pm$ and assumed $\kappa\beta = 1$. We indicate by – when the cross section is negligible

ℓq coupling	$M_{\rm lq} = 200$ GeV	250 GeV	300 GeV	350 GeV
$e^{\pm}u$	153./237.	30.9/53.1	6.6/13.0	–/3.23
$e^{\pm}d$	153./225.	29./50.1	6.2/12.0	–/3.00

TABLE III. Total cross section in fb for the pair production leptoquarks that couples only to ℓq pairs for several leptoquark masses and center–of–mass energies of 1.8/2.0 TeV. We imposed the same cuts as in Table II.

Class	$\sigma_{\rm total}$(1.8 TeV) (fb)	$\sigma_{\rm total}$(2.0 TeV) (fb)
QCD	67.	129.
electroweak	453.	562.
top	3.9	52.

TABLE IV. Total cross section in fb of the different background classes for center–of–mass energies of 1.8 and 2.0 TeV. We required one $e^{\pm}$ with $p_T > 50$ GeV and the other $e^{\mp}$ with $p_T > 20$ GeV. We also demanded that the invariant mass of e^+e^- pair differs from the Z mass by more than 5 GeV.

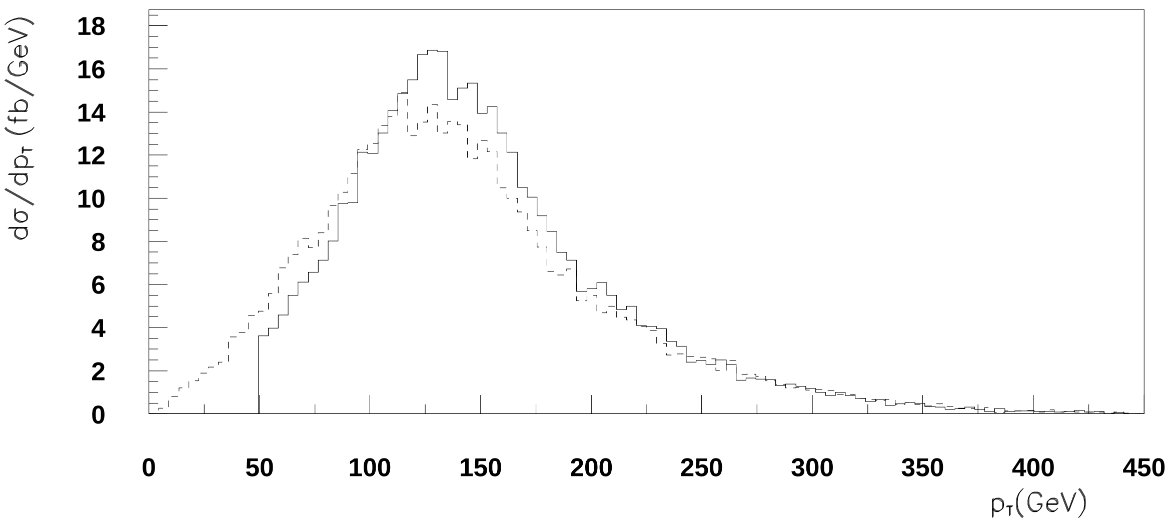

FIG. 1. p_T spectrum of the largest transverse momentum $e^{\pm}$ (solid line) and jet (dashed line). We added the single and double productions of ue^+ leptoquarks with mass $M_{\rm lq}$ = 300 GeV for $\sqrt{s} = 2.0$ TeV, $\kappa = 1$, and $\beta = 1$.

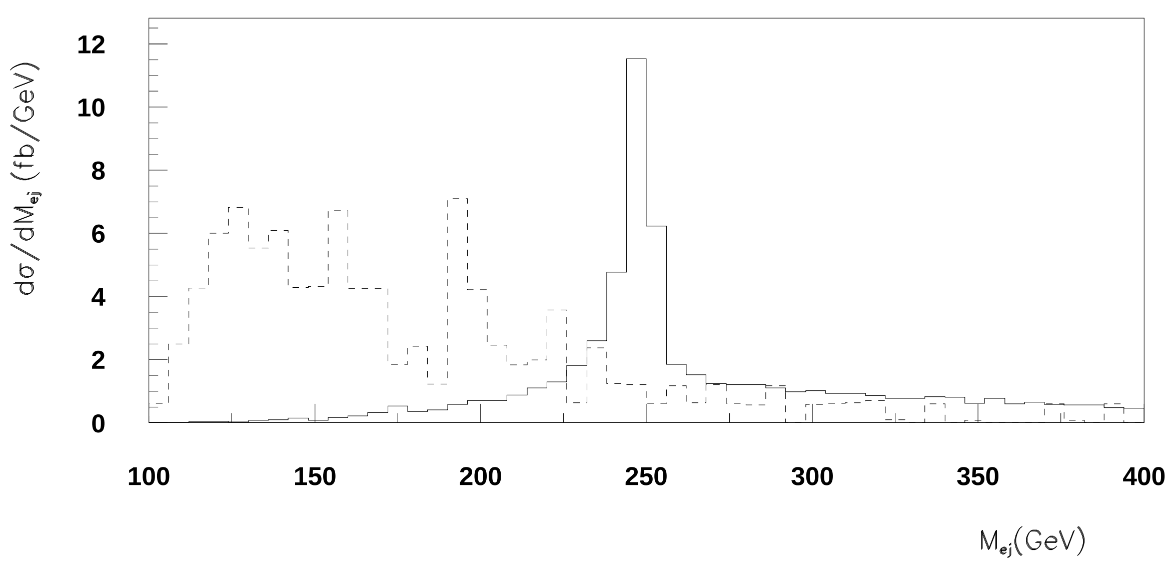

FIG. 2. M_{ej} spectrum due to the background (dashed line) and a leptoquark of mass 250 GeV with $\kappa = 1$ and $\beta = 1$ (solid line) after the cuts (C1)–(C6) are applied for $\sqrt{s} = 1.8$ TeV.

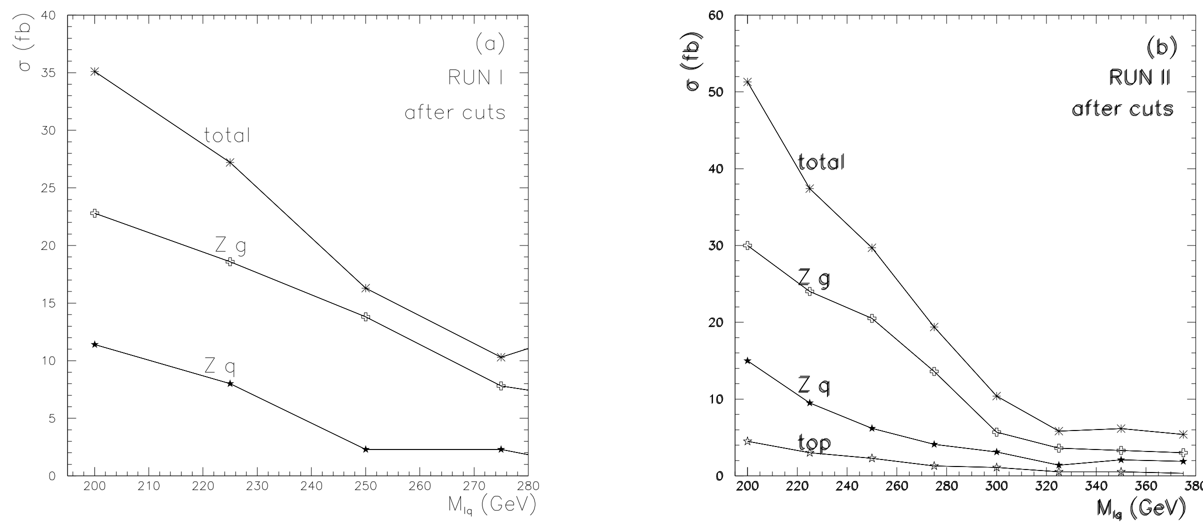

FIG. 3. Total cross sections of the main backgrounds after cuts for (a) $\sqrt{s} = 1.8$ and (b) 2.0 TeV. The line labeled Zg (Zq) stands for the reaction $q\bar{q} \to Zg$ ($qg \to Zq$) while the line marked top represents the cross section for the production of top pairs.

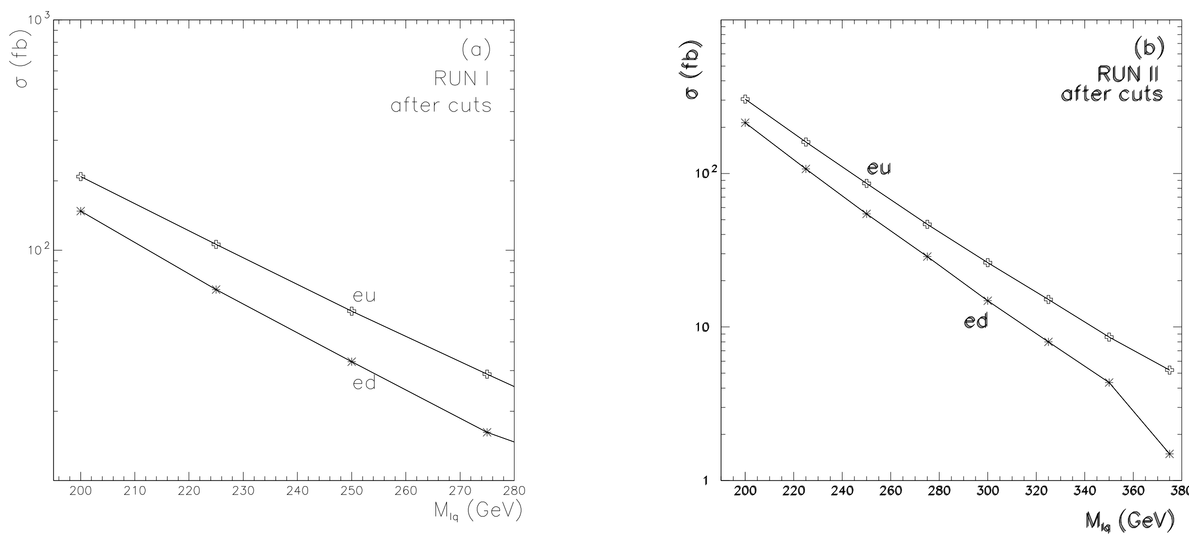

FIG. 4. Total cross sections for the production of e^+u and e^+d leptoquarks after cuts for (a) $\sqrt{s} = 1.8$ and (b) 2.0 TeV. We assumed $\kappa = 1$ and $\beta = 1$.

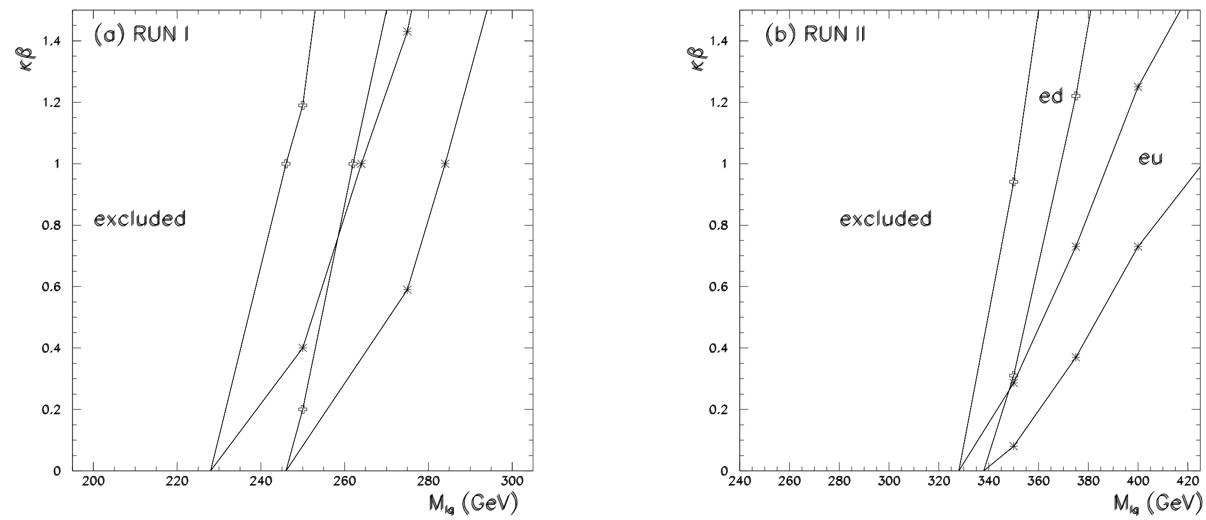

FIG. 5. 95% CL excluded region in the $\kappa\beta \otimes M_{\rm lq}$ for (a) $\sqrt{s} = 1.8$ and (b) 2.0 TeV. The curves with crosses (stars) correspond to the bounds on $e^{\pm}d$ ($e^{\pm}u$) leptoquarks, with the upper (lower) one originating from the results of a single (combined) experiment(s).

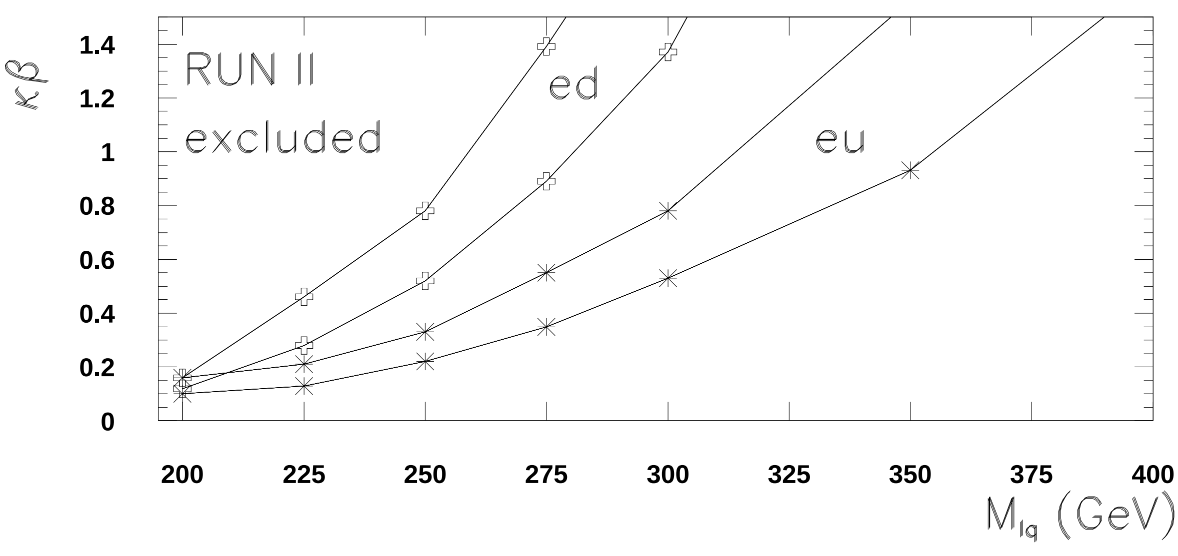

FIG. 6. 95% CL excluded region in the $\kappa\beta \otimes M_{\rm lq}$ for $\sqrt{s} = 2.0$ TeV when we impose cuts (C1)–(C7) and also demand that the events exhibit just one jet. The curves with crosses (stars) correspond to the bounds on $e^{\pm}d$ ($e^{\pm}u$) leptoquarks, with the upper (lower) one originating from the results of a single (combined) experiment(s).